Evaluation of a Fog Detect & Warning System Using a Vehicle Simulator

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ABSTRACT

While the difference in temperatures at the earth's surface between day and night leads to flatland fog from night to early morning, mountain fog sets in when damp air rises along the slope of mountains. In a foggy day, visible distances depend greatly on the ever-changing concentration of fog. Most of chained rear-end collisions in a foggy day are caused by significant differences in speeds between vehicles. Then, it is important to minimize the collisions in fog. Fog Detect & Warning System (FDWS) was conceived to provide safety operating speeds and inter-vehicle safety distances to drivers in a foggy day through text messages, color codes, and others.

The objective of this study is to estimate the effects of FDWS on drivers' safety behaviors with a vehicle simulator and a questionnaire survey. A roadway section 1 km long with bidirectional 2 lanes was chosen for the estimation efforts. The test segment was configured from the Munsan to the Jeokseong county in National Highway 37. Scenarios associated with fog were set as heavy fog (a visible distance of 30 m) and light fog (a visible distance of 80 m). Also, the distance between driver warning lamps was considered by 25 m and 30 m, respectively. The experiment conducted in this study employed the total of 31 adults who were randomly selected from 20- to 60-year old. Before performing the experiment, each subject had enough times to be familiar with the vehicle simulator and was instructed by the guideline of the experiment. After performing the main test, a questionnaire survey was undertaken for each subject.

It is expected that FDWS will be implemented in National Highway 37 after determining if FDWS appears to have safety effects with performing complementary and inspectional steps. A follow-up study will be conducted to estimate actual effects on which FDWS has on driver's behaviors in a pilot roadway.

1. Introduction

Fog that is familiar with us is generated from night to early morning due to the difference in temperature at the earth's surface between day and night. Mountain fog is generated when damp air rises along the slope of mountains regardless of specific conditions like day and night. Because visible distances in fog can be varied by the concentration of fog, the fog significantly affects safe driving. For the actual figure in traffic collisions according to the condition of weather, although the number of collisions in fine days increased compared to other weather conditions,

Foggy days have average fatal collision rates of 18.8 collision year, which fine days have average fatal collision rate of 12.2 collision year. Also, the foggy days appear of have fatal collision0 rates than grey and rainy days. In spite of all the danger in foggy roads, the facilities that guarantee visible distances in fog are insufficient in Korea, and road signs and information providing systems are also unsatisfactory. In addition, fatal collisions caused by fog have been increased due to the lack of the proper application based on the experience of road manages in the design and installation of facilities at the early stage of these processes.

Thus, this study develops a Fog Detect & Warning System (FDWS) and evaluates the effects of this system with a driving simulator. Fillally, this study is aimed at conceiving the way of develops making vehicles safely in foggy days through installing the system in actual roads.

2. Tendency in the traffic collision by weather conditions

According to the data presented by the Road Traffic Authority (Statistics on traffic collisions in 2008) that represents the tendency in traffic collisions during the last six years according to weather conditions except for unclassified and unidentified cases, a large part of collisions, about 83%, occurred in fine days, and the second highest rate was 9.39% in rainy days, 6.42% in grey days, 0.95% in snow days, and 0.21% in foggy days. In the fatal collision rate in these collisions according to weather conditions, fine days, clouded days, rainy days, foggy days, and snow days showed 2.76%, 4.16%, 3.61%, 13.41%, and 2.99%, respectively, in which the foggy days represented the highest fatal collision rate in these conditions. It can be seen that a certain abnormal weather condition, such as a foggy day, may bring huge collisions like chained rear-end collisions and large number of victims in such collisions.

Table 1 Tendency in the traffic collisions by weather conditions (Unit: cases)

Weather Condition Year	Sum		Fine Days		Grey Days		Rainy Days		Foggy Days		Snow Days	
	Cases	Fatal	Cases	Fatal	Cases	Fatal	Cases	Fatal	Cases	Fatal	Cases	Fatal

2002	231,026	7,222	207,778	6,151	9,176	376	12,548	596	423	40	1,101	59
2003	240,104	7,212	181,503	5,026	23,127	869	32,439	1,122	191	96	2,844	99
2004	220,755	6,563	182,021	5,145	14,133	594	21,463	705	606	61	2,532	58
2005	212,712	6,341	179,009	5,019	12,881	582	17,361	619	404	44	3,057	77
2006	212,400	5,700	177,447	4,328	12,487	554	20,168	706	566	75	1,732	37
2007	210,560	6,153	174,561	4,733	13,405	570	20,704	751	562	53	1,328	46
Total	1,327,557	39,191	1,102,319	30,402	85,209	3,545	124,683	4,499	2,752	369	12,594	376

3. Literature reviews

In the handbook of traffic safety facilities (National Police Agency, 2000), a warning sign of fog is to apply to roads that appear to have particular weather conditions like a heavy fog. Also, information on fog and speed limitations are provided to drivers by the Variable Message Sign (VMS) that is installed as a part of traffic management systems.

Fig. 1 Warning sign in fog areas

Fig. 2 Electronic display board

In addition, lights that show no scattering within a specific angle are installed at a position below 2m in order to guarantee a visible distance of drivers in frequent fog areas.

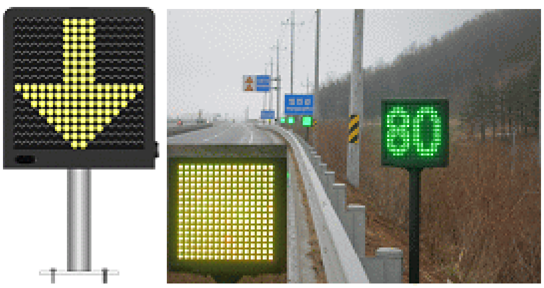
Also, fog warning systems that inform precaution on fog to drivers using flash lights and horns and lane departure warning systems, such as bumpy road pavement or projected lane installed on a road shoulder, that stimulate awareness on lane departure to drivers are used for such particular conditions.

In the case of other countries, Cooper & Sawyer (England, 2005) installed a fog warning system in highways and investigated its effects in the study on fog warning systems. They installed 54 fog detectors in fog areas. In the case of the visible distance that is presented by below 250m, a “FOG” message was presented at the VMS, which was installed at 0.8～2.2km ahead in a fog area. It represented no evidence of safety effects in the VMS warning message for good load conditions. However, in the case of bad road conditions with curved sections, it showed that drivers well obeyed to the VMS warning message. In the comparison between the VMS message with 80km/h and the VMS+"slippery road" symbol with 60km/h, the average speed decreased by 2.5km/h, and the inter-vehicle distance determined by below 1 second showed a decrease in the speed by 18%. Thus, a method that applies both the VMS message with speeds and the warning message, which shows the conditions of forward areas, is a more effective way than that of regular fixed signs.

4. Fog Detect & Warning System (FDWS)

The FDWS presents proper driving speeds and inter-vehicle distances to drivers using numbers or surface emission devices in order to prevent traffic collisions caused by over-speed driving and lack of inter-vehicle safety distance in fog areas.

The installation distance of the Light Bar Type1 is determined by 25m or 30m in which the Light Bar Type1 consists of specific warning devices as shown in Fig. 3 for maintaining safety driving speeds and inter-vehicle distances in fog areas.



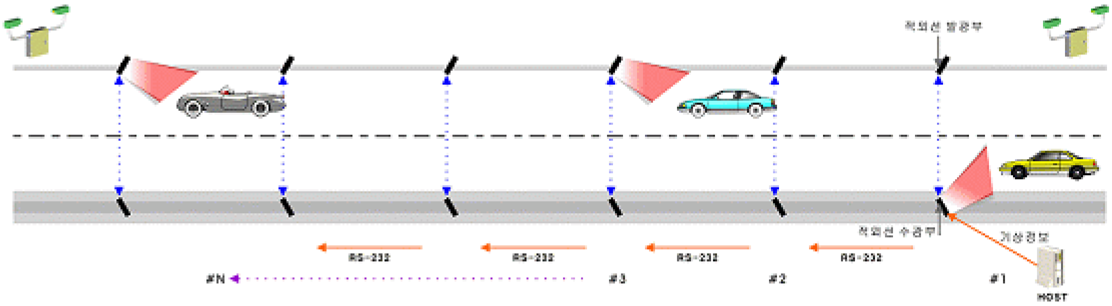


Fig. 3 Configuration of the Light Bar (Type 1)

The installation distance of the Light Bar Type2 is installed at the internals ofby 25m or 30m in which the Light Bar Type2 notifies the presence of vehicles ahead of drivers in fog areas by presenting the location of forward vehicles. It shows a high visibility with high brightness LEDs, which are used as the major light source and make possible to see objects from a distance. Also, in the case of the auxiliary light source, it uses low brightness LEDs to minimize the blinding of drivers and adds a surface emission function for playing a role in guidance lights.

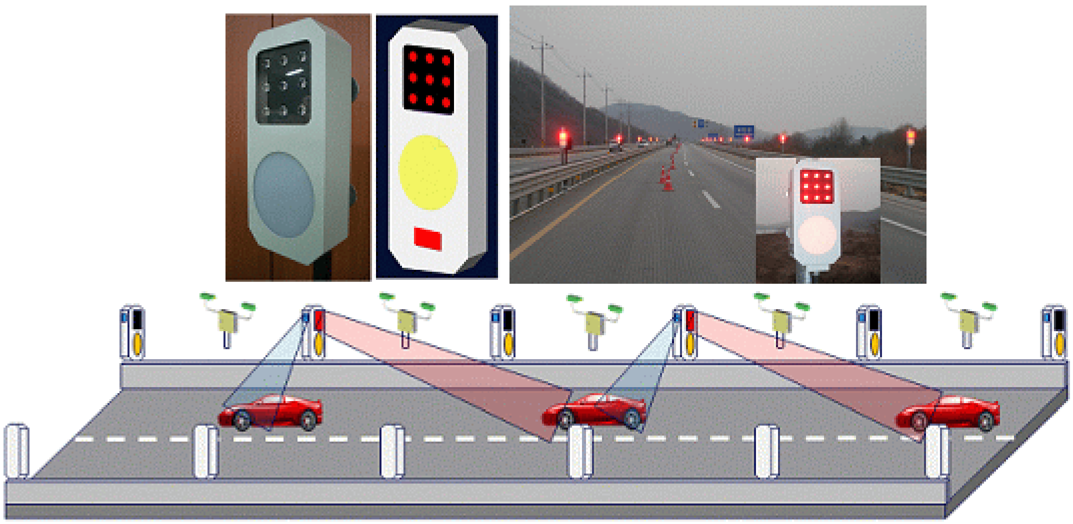


Fig. 4 Configuration of the Light Bar (Type 2)

5. Virtual driving test

A test segment used in the virtual driving test was selected as a 1km long segment around the Nulnochun bridge in National Highway 37 that is a bidirectional road with two lanes from Munsan to Jeokseong. The objective of this test is to analyze proper driving speeds and inter-vehicle distances according to visible distances in fog areas.

Fig. 5 Test segment

The road simulator, K-ROADS, developed by the Korea Institute of Construction Technology was used to evaluate the effietiveness of FDWS of drivers during the driving based on the FDWS. Fig. 6 represents the K-ROADS, and Fig. 7 and Fig. 8 show the computer graphic images performed by using a virtual reality in fog areas.

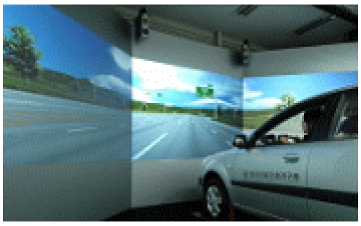


Fig. 6 K-ROADS	Fig. 7 Type 1	Fig. 8 Type 2

(1) Summary of the test

- Test segment: National Highway 37, Munsan-Jeoksung, 1km long segment around the Nulnochun bridge
- Subjects: 30 adult males and females (corrected eye sight more than 0.7, actual driving experience more than 1 year with a driver's license)
- Scenario
  ① Time of the virtual road: Early morning in a frequent fog road
  ② Fog condition: Thick fog (visible distance: 30m), thin fog (visible distance: 80m)
- Condition of the TYPE 1: No precedence vehicles, yellow limit speed+surface emission effects
- Condition of the TYPE 2: Notifying vehicles to rear vehicles by using the major light source through lighting it after detecting vehicles
- Test procedure: Introduction to the test, training for the simulator, and explaining the

subject and objective of the test including details in the test

- FDWS driving test: Driving as a usual manner and obtaining driving data from the test
- Subjective survey: After completing all driving tests, a questionnaire survey is undertaken for each subject in order to investigate the subjective psychological state of the participants

(2) Analysis of the driving data

In the analysis of driving patterns, the driving patterns were first investigated using the driving speed and inter-vehicle graphs for the test segment. Second, the difference in the response rate of drivers for the installation distance of warning lights was analyzed. Then, a general accommodation rate was analyzed for the system. Based on the results of the analysis, it was analyzed that whether the system contributes to the visibility and safety driving for drivers.

(2-1) Obtained data

Light bar(Type 1)

In the driving test for 31 subjects, a total of 31 individual speed data were obtained by visible distances as noted in Table 2.

Table 2 Obtained data in the Light bar (Type 1)

Light bar (Type 1)		Number of available data for the analysis	Number of lost data	Total number of data
Visible Distance: 30m	Installation distance: 25m	31	0	31
	Installation distance: 30m	31	0	31
Visible Distance: 80m	Installation distance: 25m	31	0	31
	Installation distance: 30m	31	0	31

② Light bar(Type 2)

In the driving test for 31 subjects, the speed data and inter-vehicle data that can be analyzed according to visible distances are summarized in Table 3. The criteria for removing data can be determined as follows: first, there are no followings to precedence vehicles; second, the behavior of a lead vehicle comes into or out the middle of the analysis segment; and third, the difference in driving speeds between the maximum and the minimum values in an analysis section represents

more than 20km/h. Then, the data corresponded to these criteria was removed as improper data.

Table 3 Obtained data in the Light bar (Type 2)

Light bar (Type 2)		Number of available data for the analysis	Number of removed data	Total number of data
Visible Distance: 30m	Installation distance: 30m	13	18	31
	Installation distance: 25m	16	15	31
Visible Distance: 80m	Installation distance: 30m	8	23	31
	Installation distance: 25m	17	14	31

(2-2) Analysis of the driving patterns of drivers in the FDWS

① Light bar(Type 1)

Driving patterns of the subjects were analyzed according to given fog conditions. In the thick fog condition with the visible distance of 30m and speed limit of 30km/h, subjects increased their driving speeds and decreased speeds about 10km/h after passing a distance of 1650m in which the system is installed. In the case of the thin fog condition with the visible distance of 50m and speed limit of 50km/h, there were no differences in driving speeds at the point of 1650m where the system was installed before and after passing the point.

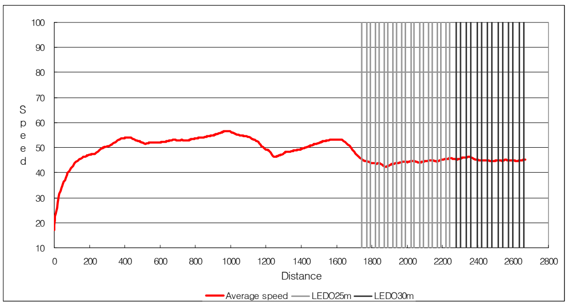


Fig. 8 Light bar
(Type1: Visible Distance - 30m)

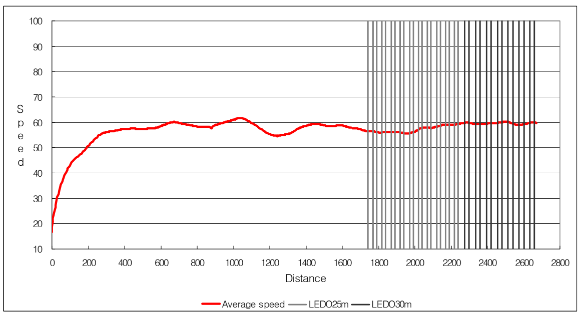


Fig. 9 Light bar
(Type1: Visible Distance - 80m)

② Light bar(Type 2),

In the investigation of the driving patterns of drivers using inter-vehicle distances for each fog condition, the driving patterns for the thick fog condition with the visible distance of 30m and speed limit of 30km/h and the thick fog condition with the visible distance of 50m and speed limit of

50km/h represented similar results.

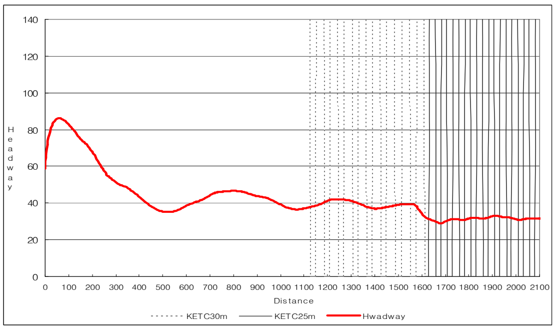
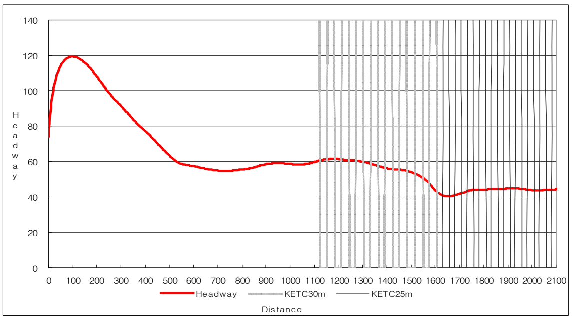
	

Fig. 10 Light bar (Type 2: Visible Distance - 30m)	Fig. 11 Light bar (Type2: Visible Distance - 80m)

(2-3) Analysis of the installation distance of the warning lights for drivers in the FDWS

① Light bar(Type 1)

For the Light bar (Type 1), tests on the difference in the average speed in test sections that was caused by the installation distance of the warning lights for drivers in which the lights were installed with the intervals of 25m and 30m were verified under the conditions of the visible distance of 30m and speed limit of 30km/h and the visible distance of 80m and speed limits of 50km/h. Since the sample data did not satisfy the normality, a non-parametric statistical test method was used. The hypothesis used in this test can be determined as follows:

$$H_0 : \mu_{25} = \mu_{30} \qquad\qquad H_1 : \mu_{25} \neq \mu_{30}$$

Since the significant probabilities in the two cases with visible distances of 30m and 80m were 0.000 and that were smaller than the value of α=0.05, the null hypothesis that determines the same average driving speed for the installation distances of 25m and 30m was rejected. It is considered that the average driving speeds in installed sections are different. However, it is also difficult to regard which installation distance, 25m or 30m, is safe in driving only based on the results of the non-parametric statistical test. It is important to perform even driving including the low driving speed in fog conditions. Thus, this study investigated the distribution of the samples according to the installation distances. The speed distributions in the installation distance of 25m and 30m were 4.41 and 0.21, respectively, in which the installation distance of 30m represented a smaller distribution than that of the distance of 25m. It seems that drivers in the installation distance of 30m showed more even driving behaviors than the installation distance of 25m. However, with the rescues it is necessary to consider the results obtained from the adaptation in the system through the driving.

② Light bar(Type 2)

It is necessary to establish a reference for the minimum inter-vehicle distance for the safety of drivers in foggy days because the Light bar (Type 2) evaluates the effects of the system based on the inter-vehicle distance differed from the Light bar (Type 1).

Thus, this study deduced the minimum inter-vehicle distance using a stopping sight distance formula. In the assumption in which the braking distance of a precedence vehicle during the driving shows the same braking distance as of following vehicles, the inter-vehicle distance was calculated by considering the free running distance only except for the braking distance, and the time (t) in the free running distance was obtained as an inter-vehicle distance per speed through applying the recognition time of 2.5 seconds.

$$\text{minimum headway distance} = \text{speed}(\frac{\text{km}}{\text{h}}) \times \frac{1}{3.6} \times 2.5\text{s}$$

The test groups were classified into two groups. One does correspond to the minimum inter-vehicle distance, and the other does not for the data that was to be analyzed by using the deduced equation.

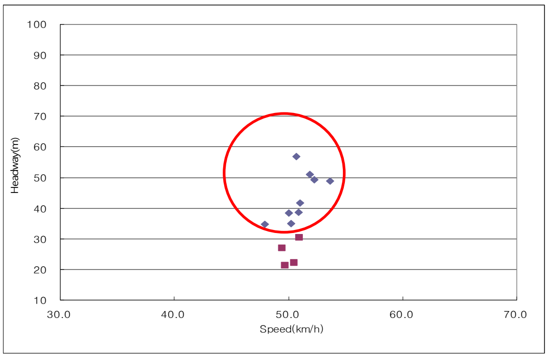


Fig. 12 Installation distance - 30m (visible distance: 30m)

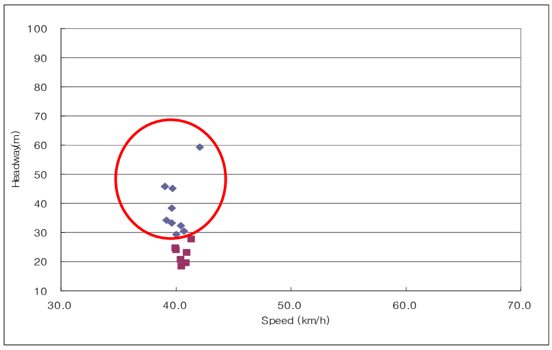


Fig. 13 Installation distance - 25m (visible distance: 25m)

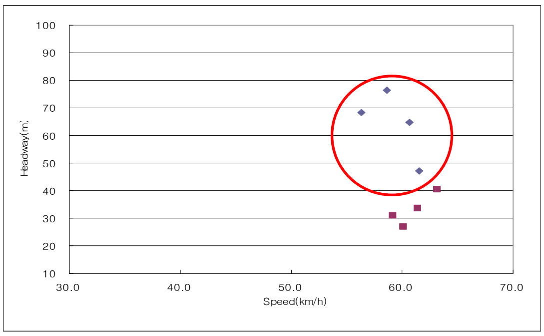


Fig. 14 Installation distance - 30m (visible distance: 80m)

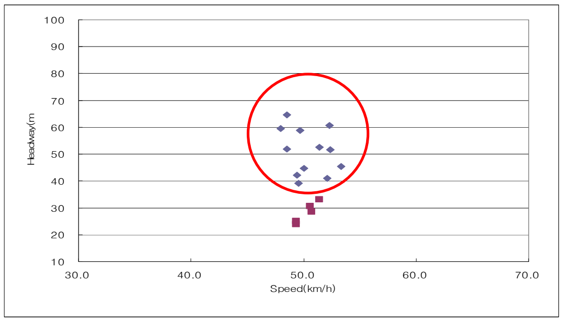


Fig. 15 Installation distance - 25m (visible distance: 80m)

This study compared and analyzed the data that maintained the minimum inter-vehicle distance in order to statistically investigate the difference in the installation distances of the warning lights for

drivers according to the visible distance in the Light bar (Type 2).

In the test of the data, an independent sample test was used. Also, in the test of the normality of the samples before applying the test, the analysis was applied because all the results were satisfied. The hypothesis on the independent sample test was determined as follows:

$$H_0 : \mu_{25} = \mu_{30} \qquad H_1 : \mu_{25} \neq \mu_{30}$$

An assumption that showed the same distributions in two samples because the significant probability in an equivalent distribution test represented 0.73 and 0.64, respectively, in the visible distances of 30m and 80m and that was larger than the significant level, $\alpha=0.05$ was established. Also, in the results of the independent sample test, because the significant probability in the case with the visible distance of 30m showed 0.23 and that was larger than the significant level, $\alpha=0.05$, it can be seen that there were no differences in the results due to the installation distance. In the condition with the visible distance of 80m, because the significant possibility in an independent sample test represented 0.03 and that was smaller than the significant level, $\alpha=0.05$, there were certain differences in the results due to the installation distance. However, it is necessary to reflect the lack of reliability in the results of the analysis due to the small number of data that are to be analyzed compared to that of the case with the visible distance of 30m.

(2-4) Accommodation rate of the FDWS

① Light bar (TYPE 1)

This study deduced the accommodation rate of the system based on the subjects related to the decrease in driving speeds, which showed more than 5km/h, compared with the initial driving speed after the experience of the FDWS in fog roads through the simulator. The deduced accommodation rate can be determined as follows:

- For the visible distance of 30m: The accommodation rate was 71% by the margin of error as ±0.16 at the confidence level of 95%.
- For the visible distance of 80m: The accommodation rate was 45% by the margin of error as ±0.18 at the confidence level of 95%.

② Light bar (TYPE 2)

This study deduced the accommodation rate of the system based on the subjects who maintained the minimum inter-vehicle distance in the FDWS in fog roads. The deduced accommodation rate can be determined as follows:

- For the visible distance of 30m: It was investigated that the accommodation rate of the inter-vehicle distance of the subjects showed 69% by the margin of error as ±0.25 at the confidence level of 95% for a total of 13 data in the installation distance of 30m. In the case of the installation distance of 25m, the accommodation rate showed 56% by

the margin of error as ±0.24 at the confidence level of 95% for a total of 16 data.

- For the visible distance of 80m: It can be considered that the accommodation rate in the installation distance of 30m showed 50% by the margin of error as ±0.34 at the confidence level of 95% for a total of 8 data. Also, in the case of the installation distance of 25m, the accommodation rate represented 71% by the margin of error as ±0.21 at the confidence level of 95% for a total of 8 data.

In the comparison of the difference in the characteristics of fog between the simulator and the actual road, it can be seen that the fog experienced in the simulator may affect the driver's behavior in actual fog roads through considering the accommodation rate obtained in the test.

In the comparison of the system accommodation rates in the Type 1 and Type 2, the accommodation rate of the Type 2 that represents inter-vehicle distances showed higher rates than that of the Type 1 that shows speed limits. It shows that the system that guides the inter-vehicle distance may help the safe driving of drivers compared to the system that guides speed limits in fog roads.

6. Conclusion

This study proposed the FDWS to guide safe driving by maintaining driving speeds and inter-vehicle distances in fog roads and verified the effects of this system through some experiments with a simulator. This study first investigated general driving patterns and analyzed the differences in the speeds of the warning lights for drivers and the inter-vehicle distances in the system. Then, this study investigated whether the drivers accommodated to the system after experiencing this system.

As a result, there were no specific differences in driving speeds and inter-vehicle distances according to the installation distances of warning lights. Also, it was considered that the system was effective for fog conditions because the Type 1 and Type 2 employed in the FDWS represented high accommodation rates more than 50%.

In future studies, the effects of the system will be verified by some drivers in actual fog conditions by installing practical samples to a TEST BED based on the results of the experiments performed in the simulator after compensating the reliability through expanding the number of subjects.

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